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Neutrosophic Hypothesis to Validate the Efficacy and Safety of Propolis in the Treatment of External Bacterial Otitis in Canines

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Abstract. Propolis, known for its antibacterial, antifungal, antioxidant, antiviral, immunomodulatory, and anti-parasitic properties, has been the subject of this study to evaluate its efficacy and safety in the treatment of bacterial external otitis in domestic canines. Through questionnaires administered to veterinary experts and the use of neutrosophic logic for hypothesis testing, perceptions based on clinical experiences and scientific literature were analyzed. The results indicate strong agreement that propolis is effective and safe, surpassing some aspects of conventional antibiotic treatments and demonstrating high tolerability without serious side effects. This acceptance underscores its potential as a natural alternative in veterinary treatments, particularly valuable in cases of antimicrobial resistance or allergies to traditional medications. This study provides significant evidence supporting the integration of propolis into veterinary practices, suggesting the need for further research and possible revisions of current clinical practices for managing bacterial conditions in animals. The use of neutrosophic hypotheses facilitated a more detailed and deeply informed interpretation of the level of expert agreement on the properties of propolis in the condition analyzed.

Keywords: propolis, external bacterial otitis, domestic canines, neutrosophic hypothesis.

1 Introduction

The indiscriminate use of antibiotics in both human medicine and veterinary medicine has induced side effects ranging from mild to severe, significantly contributing to the emergence of bacterial strains with multiple resistances to these medications [1]. Microbial adaptability has led to the frequent need to modify initial therapeutic regimens, due to the progressive reduction of the effectiveness of antibiotic drugs [2]. In this context, the use of propolis, an apiary derivative of a resinous nature and complex composition, has been proposed. This natural product presents variations in its coloration, ranging from ochre and red to light brown and green, and in its texture, which varies from friable and firm to gummy and elastic. [3]

Propolis has been extensively studied for its antibacterial properties, and it has also been found to have antifungal, antioxidant, antiviral, immunomodulatory, and anti-parasitic capabilities [4]. Recent research has linked these beneficial properties to the presence of terpenoids, flavonoids, and anthraquinones in its composition. [5]

External otitis is characterized by an inflammation of the skin lining the external auditory canal and, sometimes, the ear pinna. When this condition is not effectively resolved, it can evolve into a chronic form and, in unfortunate situations, compromise the tympanic membrane, extending the infection to the middle ear [6]. This pathology results from a confluence of etiological factors that include ectoparasites, allergic conditions, dermatological problems, endocrine disorders, and the presence of foreign bodies. The persistence of the inflammatory process in the outer ear for a period longer than six months is defined as chronic external otitis. [7]

Both Gram-positive and Gram-negative bacteria play a crucial role as etiological agents in ear infectious processes. These microorganisms, which include species such as *Staphylococcus intermedius* and *Pseudomonas aeruginosa*, are commonly identified in chronic otic infections and can coexist as part of the normal microbiota of the auditory canal. Despite their usual presence in this environment, under certain conditions, such as a significant increase in their population density or a decrease in local defenses, they can become opportunistic pathogens and cause diseases. [8]

In particular, *Staphylococcus intermedius* is frequently associated with infections in canines, showing a notable adaptation to this host [9]. On the other hand, *Pseudomonas aeruginosa* is known for its resistance to multiple antibiotics and its ability to colonize moist environments, making it a formidable pathogen in cases of external otitis, especially in chronic and recurrent forms.

Besides these main pathogens, other bacteria such as *Proteus mirabilis*, *Escherichia coli*, *Corynebacterium*

spp., Enterococcus spp., and Streptococcus spp. also contribute to the etiology of otitis, although their involvement is relatively less frequent. These microorganisms can be part of the commensal or transient flora of the auditory canal, but under conducive conditions, such as alterations in the normal microflora or changes in host immunity, they can cause infections.

Propolis is a waxy substance produced by bees from resinous exudates collected from various plants. This resin is used by bees not only for the construction and repair of their hives but also as a defense mechanism to seal openings and protect the hive from external elements. Currently, scientific interest in propolis has significantly increased, especially in fields like biology and medicine, where its potential as a dietary supplement and its applicability in the pharmaceutical industry are explored. [10]

Historically, the use of propolis dates back to ancient civilizations such as the Greeks, Romans, and Egyptians, who used it to treat medical conditions, including bacterial infections. This traditional use has persisted to the present day within alternative medicine, where propolis continues to be valued for its therapeutic properties, particularly its antibacterial activity.

The relevance of propolis in contemporary medicine is based on its rich biochemical composition, which includes compounds such as flavonoids, terpenoids, and phenolics, known for their antioxidant, anti-inflammatory, antibacterial, and antifungal properties. Recent studies have expanded our understanding of how these compounds can contribute to managing infectious and chronic diseases, providing a scientific basis for their integration into more modern and effective treatments. Given this context, ongoing research is essential to scientifically validate the use of propolis in clinical contexts, establish precise dosages, and explore its mechanisms of action at the cellular and molecular levels. This could facilitate its acceptance and regulation as a component in medicines and nutritional supplements, thereby broadening its potential use in public health and therapeutics.

Informed decision-making in veterinary medicine, especially in the treatment of conditions like bacterial external otitis in domestic canines, requires a comprehensive and nuanced approach due to the complexity and variability of the clinical factors involved. In this context, the neutrosophic logic proposed by Florentin Smarandache offers a promising theoretical framework by allowing the integration of elements of truth, falsehood, and indeterminacy in the analysis of information and uncertain situations that often arise in clinical practice. [11][12]

External Bacterial otitis in canines is a multifactorial condition influenced by various factors such as genetics, environment, and the presence of multiple pathogens resistant to conventional treatments. The variability in treatment response among individuals further complicates decision-making. Neutrosophic logic, by addressing the uncertainties and contradictions inherent in such cases, facilitates a more holistic and realistic approach to evaluating therapeutic options.

The theory of neutrosophy has given rise to numerous scientific disciplines, including neutrosophic logic [13], neutrosophic sets [14], neutrosophic probability, and neutrosophic statistics [15], which have found varied applications in fields such as engineering, computer science, and medical research [16][17]. In this study, a neutrosophic hypothesis is employed, which differs from traditional statistical hypotheses in that the variables describing the population's characteristics are of a neutrosophic nature. That is, they have indeterminate values, some unknown or an inexact number of terms if the variable is discrete, or at least one of the compared characteristics of the population is neutrosophic, characterized by being indeterminate, unknown, or vague.

Using neutrosophic logic, veterinarians can consider not only the expected outcomes (truth) and the possible adverse effects or failures of the treatment (falsehood) but also states of indetermination [18], such as the unpredictable reactions of the patient to treatment or the unknown interaction between concurrent medications. This allows for a more comprehensive assessment of risks and benefits, resulting in more informed and case-adapted decision-making.

Neutrosophic statistics extend this approach to data analysis, incorporating the indetermination and uncertainty of the real world into statistical interpretation [19], [20]. In researching and treating various conditions, neutrosophic statistics can be used to analyze the efficacy of different therapeutic interventions, considering not only typical responses to treatment but also inexplicable anomalies and variations. [21]

In this sense, the proposed study aims to collect and analyze the perceptions of veterinary experts on the antimicrobial and healing qualities of propolis in managing bacterial external otitis in domestic canines. This approach seeks to improve the precision and personalization of veterinary treatments, optimizing clinical outcomes through a more thorough and representative analysis of the variables involved.

2 Method

2.1 Methodology

This study is categorized as a quantitative exploratory study with the primary objective of evaluating the application of neutrosophic logic and statistics in determining the level of agreement among veterinary experts regarding the antimicrobial and healing utilities of propolis, as well as its efficacy and safety in the treatment of bacterial external otitis in domestic canines compared to conventional treatments. The adopted design is cross-

sectional, where data is collected and analyzed at a single point in time through a structured survey.

For data collection, a combination of simple random sampling and purposive sampling was used. Simple random sampling ensures that every member of the population of veterinarians experienced in treatments for canines has an equal probability of being selected. This approach was complemented by purposive sampling to focus on those professionals with limited access. Thus ensuring a broad and representative coverage of experienced opinions.

A survey based on the Likert format was designed, specifically created to measure the concordance among veterinary experts on various statements about multiple aspects of the use of propolis, including its efficacy, safety, and antimicrobial and healing properties in bacterial external otitis, as well as some comparisons with conventional treatments. Respondents were asked to express their degree of agreement or disagreement on a scale from "Strongly agree" to "Strongly disagree," according to the items shown in Table 1.

Table 1. Linguistic variable and Single-Valued Neutrosophic Numbers (SVNNs) Note: Source:[22]

Integer	Linguistic variable	SVNNs
0	Strongly disagree	(0, 1, 1)
1	Disagree	(0.20, 0.85, 0.80)
2	Partially Disagree	(0.40, 0.65, 0.60)
3	Neither agree or disagree	(0.50;0.5;0.50)
4	Partially agree	(0.60, 0.35, 0.40)
5	Agree	(0.8, 0.15, 0.20)
6	Strongly agree	(1, 0, 0)

The data collected through the survey were processed using neutrosophic statistics. This involved transforming the linguistic responses into a set of single-valued neutrosophic numbers, thereby allowing for the management of indetermination in the responses. This facilitated the conducting of neutrosophic hypothesis tests to assess the concordance of opinions and provide a solid basis for informed decisions. This method is particularly useful in studies where perceptions and expert evaluations play a crucial role and where responses may not be absolutely positive or negative.

Informed consent was obtained from all participants involved in the survey, ensuring the confidentiality and anonymity of their responses. All relevant ethical guidelines for research with human subjects were adhered to, guaranteeing an ethical and professional process in the collection and analysis of data. This methodological approach provides a robust framework for deeply exploring expert perceptions and applying advanced theoretical frameworks such as neutrosophic logic and statistics in the field of veterinary and precision medicine.

2.2 Single Valued Neutrosophic Sets

The implementation of single-valued neutrosophic sets (SVNS) marks a significant development within the realms of set theory and logic, offering a robust framework for accurately representing ambiguity and uncertainty. These SVNS are fundamental for precisely describing the truth, indeterminacy, and falsity of elements within a set. This capability makes them valuable tools in various sectors, including decision-making in uncertain environments, artificial intelligence, and information management, facilitating the analysis and handling of complex data in these disciplines.

Within the framework of SVNS, let us consider X as a space containing points or objects, with generic elements in X denoted by x. A single-valued neutrosophic set A in X is defined through three characteristic functions: the truth-membership function $T_A(x)$, the indeterminacy-membership function $I_A(x)$, and the falsity-membership function $F_A(x)$. Thus, an SVNS A can be formally expressed as $A = \{x, T_{A(x)}, I_{A(x)}, F_{A(x)x} \in X\}$, where $T_{A(x)}, I_{A(x)}$, and $F_{A(x)} \in [0,1]$ for each point x in X. In this way, the sum of $T_{A(x)}, I_{A(x)}$, and $F_{A(x)}$ meets the condition $0 \leq T_{A(x)} + I_{A(x)} + F_{A(x)} \leq 3$. [23]

This formalism allows each element x in the space X to be evaluated under these three metrics, thus facilitating a more nuanced and detailed understanding of its state in terms of truth, falsity, and indeterminacy. This approach not only enriches traditional set theory with an additional dimension of analysis but also optimizes decision-making and analysis processes in complex and dynamic environments.

Modeling membership functions within the range $[0,1]$ in SVNS provides increased flexibility and precision for analysis in contexts where uncertainty is a predominant element. This range ensures that the total sum of the membership functions related to truth, indeterminacy, and falsity does not exceed the maximum value of 3, thus

maintaining structural coherence within the theoretical framework of SVNS. Such methodology offers solid support for managing ambiguity and uncertainty across a wide range of application fields, facilitating a more systematic and detailed approach in situations that challenge conventional analytical methods.

A single-valued neutrosophic number (SVN number) facilitates the incorporation of linguistic variables into the analysis, allowing for a more nuanced interpretation of qualitative data and ambivalent contexts. To transform these SVN numbers into precise and clear values, a scoring function is used. This scoring function is crucial for quantifying the linguistic responses provided in surveys, thereby allowing for an accurate numerical evaluation of the opinions or perceptions expressed by respondents in each statement. This method ensures that subjective data are converted into quantifiable information, which is essential for subsequent statistical analysis and evidence-based decision-making.

$$p(x) = 2 + T(x) + I(x) + F(x) \quad (1)$$

In the context of this research, the scoring function can be mathematically expressed in the following way for each statement in the survey:

$$p(x)_s = 2 + T(x)_s + I(x)_s + F(x)_s \quad (2)$$

Where *x* represents the number of respondents, *s* is the number of statements, and $p(x)_s$ is the scoring function value of respondent *x* for statement *s*. The scoring function reflects each respondent's assessment of a specific statement based on their level of agreement or disagreement. The sum of the scores for each statement across all respondents is used to calculate the average scoring function for that specific statement.

To interpret the obtained values and assign degrees of agreement, the total possible range of the average scoring function (ranging from 0 to 3) is divided into 7 intervals. Each interval represents a specific degree of agreement or disagreement, detailed in Table 2 of the study. This segmentation allows a more granular interpretation of how respondents perceive and value each statement presented in the survey.

This method provides a solid foundation for analyzing the responses in statistical terms and enables a quantitative evaluation of opinions, which is crucial for making informed and evidence-based decisions in the context of the research.

Table 2. Intervals of the average score by agreement degree.

Linguistic variable	Interval
Strongly disagree	$0 < \bar{p}(s) \leq 0.43$
Disagree	$0.43 < \bar{p}(s) \leq 0.86$
Partially Disagree	$0.86 < \bar{p}(s) \leq 1.29$
Neither agree nor disagree	$1.29 < \bar{p}(s) \leq 1.71$
Partially agree	$1.71 < \bar{p}(s) \leq 2.14$
Agree	$2.14 < \bar{p}(s) \leq 2{,}57$
Strongly agree	$2.57 < \bar{p}(s) \leq 3$

This methodology facilitated the application of a neutral hypothesis test for the average scoring function assigned to each statement in the survey. A neutrosophic hypothesis is a statement about the neutrosophic values of one or several characteristics of a population. The distinction between classical (statistical) hypothesis and neutrosophic hypothesis is that in neutrosophic statistics, the variables describing the characteristics of the population are neutrosophic (i.e., they have some indeterminate values, several unknown values, or an imprecise number of terms if the variable is discrete), or for the compared values at least one of the population's characteristics is neutrosophic (i.e., it has an indeterminate, unclear, or vague value). Similar to classical statistics, a neutrosophic null hypothesis, denoted by NH_0, is the statement initially assumed to be true. The neutrosophic alternative hypothesis, denoted by NH_a, is the other hypothesis. When testing NH_0 versus NH_a, there are two possible outcomes: reject NH_0 (if the sample evidence strongly suggests NH_a is false), or do not reject NH_0 (if the sample does not support strong evidence against it).

As in classical statistics, this study employs the classic standard normal distribution of a random variable z, characterized by having a mean value μ=0 and a standard deviation σ=1. Applying this distribution allows for statistical inferences under conditions of normality, providing a solid basis for the comparison and analysis of data.

In the neutrosophic context, if we consider the null hypothesis about variable x, it could be established in the following way to adapt to the neutrosophic approach:

$$NH_0: \mu_x \in [a, b]$$

where [a, b] is an interval that contains the hypothetical mean value μ_x of variable x. This interval represents a range of possible values for μ_x, reflecting the nature of indeterminacy and uncertainty that characterize neutrosophic statistics. Here, a and b are values that bound the interval within which the true mean value of the variable under study is presumed to lie, allowing a margin of flexibility essential in analyses where absolute precision cannot be guaranteed due to the variability and ambiguity inherent in respondents' answers or the nature of the phenomenon under study. Therefore, the neutrosophic statistical test is:

$$z = \frac{\hat{x} - [a,b]}{s/\sqrt{n}} \quad (3)$$

A Neutrosophic P-value, similar to classical statistics, is defined as the lowest level of significance at which a null hypothesis can be rejected. However, unlike traditional statistics where the P-value is a precise number, the neutrosophic P-value is presented as a set, and in many applications, it is expressed as an interval. This approach allows for a more flexible and adaptive interpretation of data, reflecting the indeterminacy and ambiguity that often characterize real research contexts.

In this specific study, this neutrosophic statistical methodology was used to examine the degree of agreement among experts. The goal was to determine if there was at least partial agreement, using a significance level α_N that ranges between 0.90% and 0.95%. This range reflects the neutral character of the hypothesis testing carried out, highlighting the usefulness of neutrosophic statistics in managing uncertainty and making informed decisions in contexts where data may be incomplete, ambiguous, or contradictory.

By employing neutrosophic tests, it was possible to effectively assess the degree of consensus or dissent among veterinary experts regarding claims about the antimicrobial, healing, efficacy, and safety of propolis in treating bacterial external otitis in canines. This statistical approach allowed for the incorporation and management of the uncertainty and ambiguity inherent in the subjective responses of participants, providing a deeper and more nuanced analysis than with traditional statistical methods.

3 Results

For this study, a group of 62 experts in the specific field of study was selected to participate. After administering the survey to these experts, preliminary statistical data were obtained that provided an initial view of the perceptions and opinions regarding the subject under study. The results obtained are organized and presented in a frequency table, which is essential for initial interpretation and to formulate more detailed analyses later. See Table 3.

Table 3: Frequency table for the responses obtained.

Linguistic variable	Propolis is effective in reducing symptoms	Propolis has significant antimicrobial properties that justify its use in veterinary treatments.	The use of propolis in the treatment of external otitis in canines is safer than traditional antibiotic treatments	Propolis accelerates the healing process in cases of bacterial external otitis in canines, compared to other conventional treatments	The application of propolis in treatments for canines with external otitis is well tolerated by animals, without severe side effects.	I would recommend the use of propolis as an alternative to antibiotics for the treatment of bacterial external otitis in canines.
SD	0	0	0	0	0	0
D	0	0	0	1	0	0
PD	4	6	6	1	0	0
NAD	15	13	3	5	9	15
PA	3	5	23	25	13	8
A	24	25	22	20	16	16
SA	16	13	8	10	24	23

In the table presented, it's evident that a substantial majority of respondents adopt a favorable stance regarding the statements about the properties of propolis in mitigating various aspects of bacterial external otitis in canines. Specifically, categories that reflect some level of disagreement—such as "Disagree" (D), "Partially Disagree" (PD), and "Neither Agree nor Disagree" (NAD)—record the lowest frequencies during the initial phase of the study.

This pattern suggests a generally positive perception of the use of propolis among veterinary experts, indicating

recognition of its potential benefits in treating medical conditions in canines. The scarcity of responses in the disagreement categories might be indicative of an emerging consensus on the efficacy of propolis.

With the data obtained, it is possible to apply Equation 2 to calculate the average scoring functions corresponding to each survey question. This process involves a mathematical aggregation of individual responses to obtain a central measure that reflects the general trend of the data per question. Once calculated, these average scores are categorized according to the intervals specified in Table 2, thus facilitating their systematic interpretation and comparison. See Table 4.

Table 4: Average score function for each questionnaire statement

	Propolis is effective in reducing symptoms	Propolis has significant antimicrobial properties that justify its use in veterinary treatments.	The use of propolis in the treatment of external otitis in canines is safer than traditional antibiotic treatments	Propolis accelerates the healing process in cases of bacterial external otitis in canines, compared to other conventional treatments	The application of propolis in treatments for canines with external otitis is well tolerated by animals, without severe side effects.	I would recommend the use of propolis as an alternative to antibiotics for the treatment of bacterial external otitis in canines.
Average score function	2,249	2,192	2,127	2,169	2,399	2,347

Subsequently, these categorized data are graphed to enhance the understanding and visualization of the information gathered. Graphical representation allows for a more intuitive and direct interpretation of the trends and patterns within the data set, providing a visual perspective that can reveal insights not immediately apparent through numerical analysis alone.

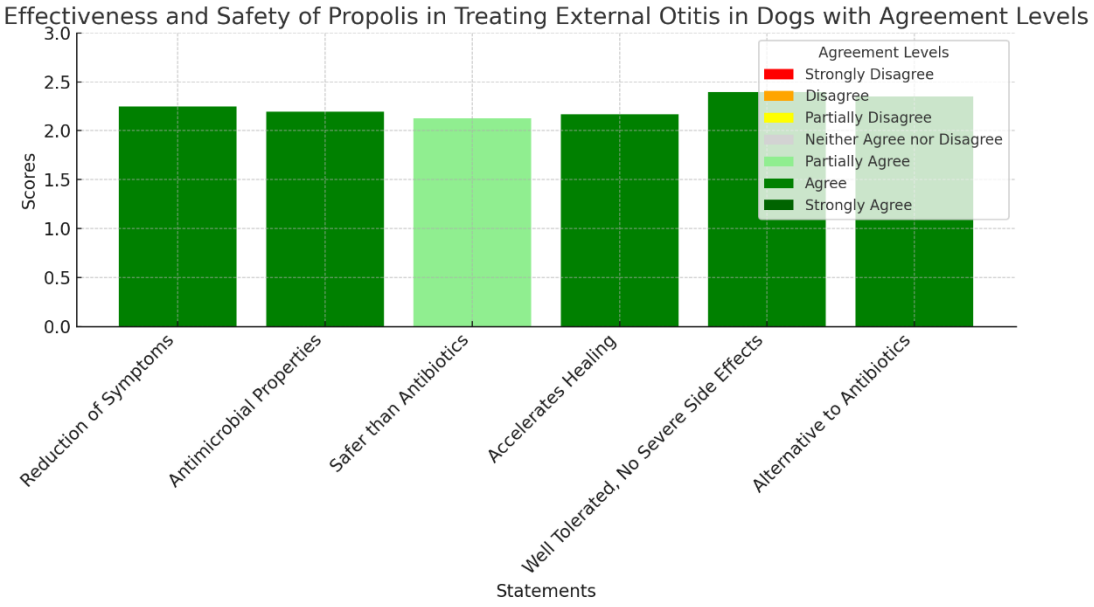

Figure 1: Effectiveness and safety of propolis according to the calculated average scoring functions

In the study conducted the average scoring function values for each statement on the questionnaire were consistently within the acceptance intervals. This indicates that, overall, the consulted experts showed favorable agreement with the proposed assertions about the properties and benefits of propolis in treating external otitis in domestic canines.

Particularly, the third statement, which claimed that "The use of propolis in the treatment of external otitis in canines is safer than traditional antibiotic treatments," scored slightly lower on average compared to the other statements on the questionnaire. While this claim was still generally accepted, the lower score suggests that there

are some reservations or a lesser degree of agreement among the experts regarding the safety of propolis compared to conventional antibiotics.

On the other hand, the rest of the statements received average scores higher than 2.14, which confirms strong concordance among the experts regarding the efficacy and tolerability of propolis. Notably, the statement that "The application of propolis in treatments for canines with external otitis is well tolerated by the animals, without severe side effects," achieved the highest average score of 2.4. This result indicates significant recognition of the tolerability and perceived safety of propolis, critical aspects in the clinical management of veterinary treatments.

The collection and analysis of these data provide valuable evidence supporting the use of propolis as a safe and effective alternative to traditional treatments for external otitis in domestic canines.

To demonstrate the claims made, as well as the overall level of agreement with respect to the study topic, the following neutral hypothesis was proposed:

$NH_0: \mu \in [0, 1.71]$

$NH_1: \mu > 1.71$

In this study, it was estimated that the sample mean corresponds to the minimum and maximum values obtained from the statements of the applied questionnaire. That is, the mean was calculated based on the range of the highest and lowest scores reported for each statement. In this case, the calculated standard deviation was 1.11. This standard deviation value indicates moderate variability in the experts' responses, reflecting differences in the perception and evaluation of propolis among the respondents:

$$z = \frac{[2.127, 2.399] - [0, 1.71]}{1.11/\sqrt{62}}$$

$$z = \frac{[0.417, 2.299]}{0.141}$$

$$z = [2.98, 2.02]$$

In the statistical analysis of the data collected from the questionnaire, a specific criterion was employed for decision-making about the null hypothesis NH_0, based on comparing the critical value with the observed test statistic. According to this criterion, NH_0 should be rejected if the minimum of the critical value exceeds the maximum of the value $\{Z_{1-\alpha N}\}$. In this case, with a significance level given as $\alpha_N = [0.05, 0.1]$, the associated critical values, calculated from standard normal distribution tables or statistical software, are in the interval [1.28, 1.64]. This means that if the test statistic calculated from the data exceeds the highest value in this range, the null hypothesis can be confidently rejected.

For the data obtained in this study, the value of the test statistic was 2.02, which is greater than the critical interval [1.28, 1.64]. Therefore, based on this analysis, NH_0 can be rejected. This implies that, statistically, there is sufficient evidence to assert that the results obtained are significantly different from what the null hypothesis had predicted, and these differences are statistically significant within the established confidence level. This result implies that the claims about the properties and effectiveness of propolis in the treatment of external otitis in canines, as valued by the experts, have statistical backing to be considered valid in clinical practices, thus supporting the integration or increased use of propolis in veterinary treatments.

4 Conclusion

This study focused on collecting and analyzing the perceptions of veterinary experts on the antimicrobial and healing qualities of propolis in managing bacterial otitis externa in domestic canines, supported by evidence derived from both clinical experience and existing scientific literature. The design and implementation of a questionnaire based on the Likert scale, which used linguistic scales, allowed for the systematic capture and evaluation of veterinarians' opinions regarding various statements about the use of propolis. The adoption of neutrosophic statistical techniques to address the uncertainty and ambiguity in respondents' answers enabled the calculation of average scores and the conduct of hypothesis tests aimed at determining the statistical relevance of the findings.

The results revealed that a large majority of experts agree that propolis is effective and safe for the treatment of external otitis in canines, surpassing certain aspects of traditional antibiotic treatments. Additionally, its good tolerability in these treatments was highlighted, demonstrating its acceptance by the animals without inducing serious side effects, an aspect of special importance in clinical settings where treatment safety is a priority.

The study provides encouraging evidence on the viability of propolis in veterinary medicine, supporting its efficacy and safety through quantitative data and expert evaluations. The use of neutrosophic hypotheses has been fundamental in effectively managing the uncertainties and indeterminacies present in expert responses, facilitating a more detailed and deeply informed interpretation of propolis properties. These findings establish a solid foundation for future research and could prompt a revision of current clinical practices in treating bacterial conditions in animals.

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